

Quasi-diffraction production of white quark–gluon clusters at superhigh-energy hadron collisions.

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Abstract

We discuss a collective effect, which can be possible in hadron–hadron collisions at superhigh energies, that is, a quasi-diffraction production of several white clusters of quarks and gluons. Being transformed into hadrons, such clusters are sources of the fastest particles, which move forward nearly parallel to each other.

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1 Hadron collisions at high and superhigh energies

The region of soft quark and gluon interactions can be considered within the approach of effective particles – constituent quarks and massive gluons. A similar idea is used in condensed matter physics, where effective particles and effective interactions are the operating tools. Reviewing the experimental data [1, 2], we can see that the hypothesis of hadrons, being composite systems of two (meson) or three (baryon) confined constituent quarks, works well.

At low and moderately high energies the constituent quarks inside a hadron, such as pion or nucleon, are spatially separated. The constituent quark of a fast-moving hadron is represented as a bunch of partons. The changes, which the clouds of colliding quarks undergo from moderately high energies up to superhigh ones, can be demonstrated in the impact parameter space (see Fig. 1) – a detailed discussion is given in [1, 2].

The figure 1a shows us a “picture” of a meson, while Fig. 1d is that for a nucleon in the impact parameter space, (*i.e.* it is how the incoming hadrons look like from the point of view of the target). In the impact parameter space quarks are black at moderately high energies: this follows from the investigation of the proportion of true inelastic and quasi-inelastic processes [3]. Accordingly, in Figs. 1a and 1d two (for a meson) and three (for a baryon) black disks are

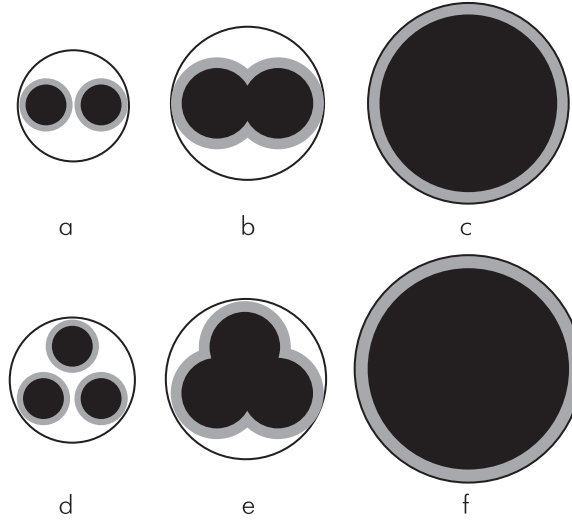


Figure 1: Quark structure of the low-lying meson (a,b,c) and baryon (d,e,f) in the constituent quark model. At moderately high energies (a,c) constituent quarks inside the hadron are spatially separated. With the energy growth quarks overlap partially (b,e); at superhigh energies (c,f) quarks completely overlap, and hadron collisions lose the additivity property.

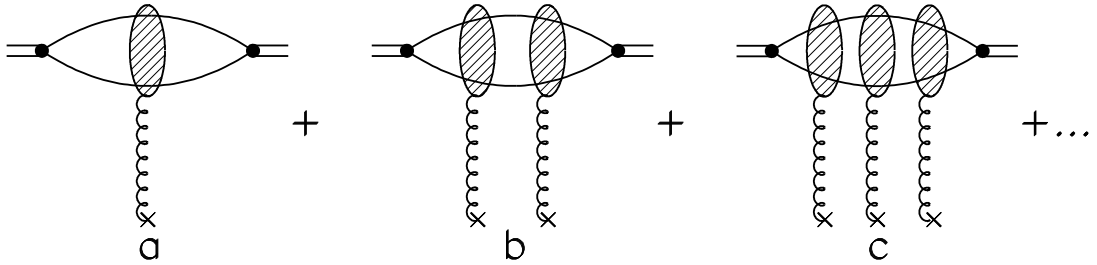


Figure 2: Multi-pomeron exchange diagrams, used for mesons in the eikonal approach [4].

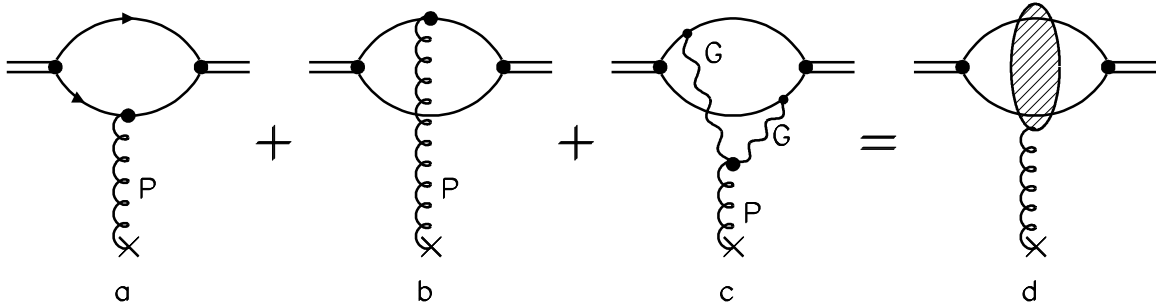


Figure 3: Vertex for pomeron-meson interaction, with **P** being a pomeron and **G** reggeized gluon used in [4]. The diagram **PGG** provides the colour screening.

drawn. But the transverse disk size increases, and at intermediate energies ($p_{lab} \sim 500 - 1000$ GeV/c) the quarks partially overlap (Figs. 1b, 1e). In this energy region the additivity may already be broken in the collision processes. Furthermore, there is a complete overlapping of clouds (Figs. 1c, 1f) and, in principle, the meson–proton and proton–proton cross sections grow up similarly, $\sigma_{tot}(p\bar{p})/\sigma_{tot}(\pi p) \rightarrow 1$ at $s \rightarrow \infty$.

The estimate of characteristics of meson–nucleon and nucleon–nucleon cross sections at increasing energies was carried out in [4] within the framework of eikonal approximation, accounting for the t -channel supercritical pomeron (**P** with $\alpha_{\mathbf{P}}(0) \sim 1.29$) and gluon–gluon–pomeron exchanges (**GGP** with $\alpha_{\mathbf{G}}(0) \sim 1.0$).

In Figs. 2,3 we demonstrate eikonal interaction for meson, analogous interaction is written for the nucleon. For energies $0.5 \text{ TeV} \leq \sqrt{s} \leq 20 \text{ TeV}$ the cross sections calculated in this way behave as follows [4]:

$$\begin{aligned}\sigma_{tot}(p\bar{p}) &= \left(49.80 + 8.16 \ln \frac{s}{9s_0} + 0.32 \ln^2 \frac{s}{9s_0} \right) \text{ mb} , & s_0 = 10^4 \text{ GeV}^2 , \\ \sigma_{tot}(\pi p) &= \left(30.31 + 5.70 \ln \frac{s}{6s_0} + 0.32 \ln^2 \frac{s}{6s_0} \right) \text{ mb} ,\end{aligned}\tag{1}$$

and

$$\begin{aligned}\sigma_{el}(p\bar{p}) &= \left(8.19 + 3.027 \ln \frac{s}{9s_0} + 0.16 \ln^2 \frac{s}{9s_0} \right) \text{ mb} , \\ \sigma_{el}(\pi p) &= \left(3.87 + 1.567 \ln \frac{s}{6s_0} + 0.16 \ln^2 \frac{s}{6s_0} \right) \text{ mb} .\end{aligned}\tag{2}$$

The calculated cross sections and other characteristics are shown in Fig. 4. In the region $\sqrt{s} \sim 10^4 \text{ GeV}$ the cosmic ray data are demonstrated, see [5] and references therein. In the region of LHC energies ($\sqrt{s} = 16 \text{ TeV}$), calculations [4] predict:

$$\sigma_{tot}(p\bar{p}) = 131 \text{ mb}, \quad \sigma_{el}(p\bar{p}) = 41 \text{ mb} .\tag{3}$$

As is seen, at LHC energies the asymptotic value $\sigma_{tot} \simeq 2\sigma_{el}$ is not reached yet.

At LHC energies another consequence of the quark overlap may reveal itself. We mean the scaling violation of proton and meson spectra in the fragmentation region, at $p/p_{max} = x \sim 1/2 - 2/3$. The hadron spectra have to decrease in this region due to the loss of quark additivity in the collision process.

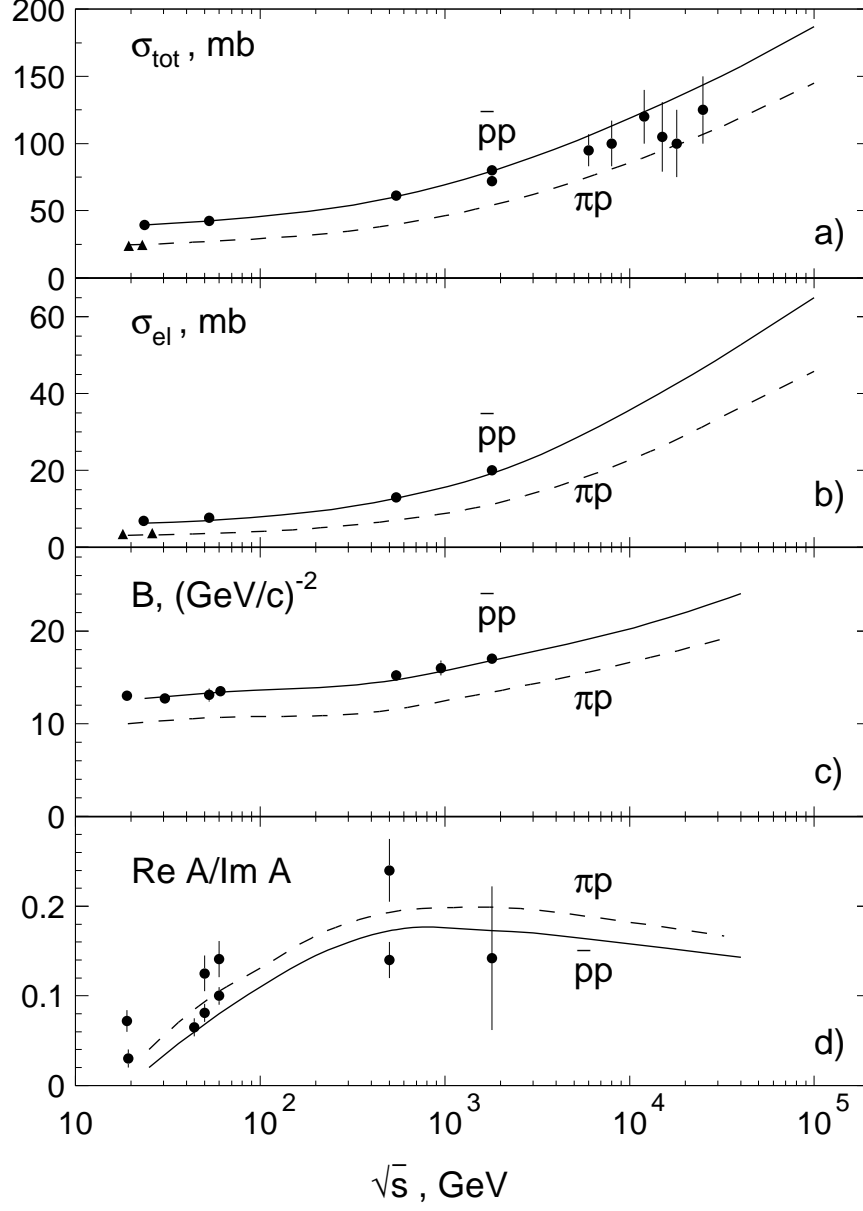


Figure 4: Calculations [4]: a) total cross sections for $p\bar{p}$ and πp collisions, b) elastic cross sections, c) diffraction scattering slopes $d\sigma_{el}/dq_{\perp}^2 = B\sigma_{el} \exp[-Bq_{\perp}^2]$, and d) ratios of real/imaginary parts of the scattering amplitudes at $q_{\perp}^2 = 0$.

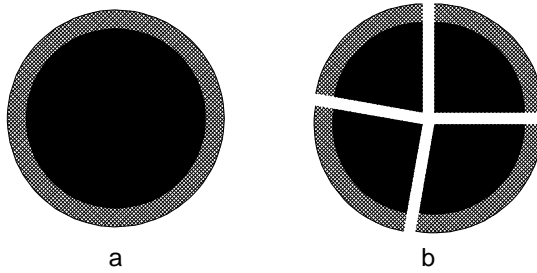


Figure 5: Variants of the behaviour of the parton black disk at superhigh energies: (a) the hadron (black disk) grows with simultaneous increase of the confinement radius, (b) the black disk increases but the growth of the confinement radius is slower, and partons split softly into several white domains (conventionally, we have separated white domains of the disk by white strips).

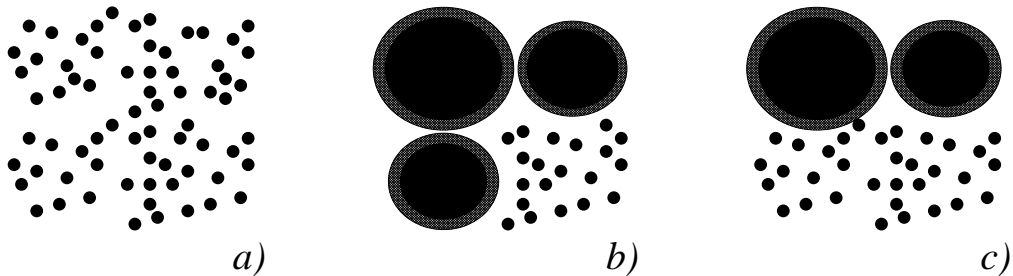


Figure 6: Probable parton distributions after collision of the disk 5a with a target (6a), and disk 5b with a target (6b,6c); the pictures 6b and 6c describe quasi-diffraction production of several white clusters of quarks and gluons. Clusters are moving forward being nearly parallel and transforming softly into hadrons.

2 Quasi-diffraction production of white quark–gluon clusters at superhigh energies

We know that the cross section $\sigma_{tot}(p\bar{p})$ grows with energy, and we are almost sure that it will continue to grow up as $\ln^2 s$. How does it affect the confinement phenomenon? Does the confinement radius also increase allowing the hadron to be a black disk (Fig. 5a) or the parton disk breaks off into a number of white domains (Fig. 5b)?

The most probable result of the interaction of the disk Fig. 5a with target is shown in Fig. 6a: it is a complete dissociation of the comb of partons with a subsequent transformation of them into the comb of hadrons.

If at superhigh energies the standard picture is such as shown in Fig. 5b, the interaction can destroy not every white domains of partons, and a large probability we face pictures of Figs. 6b,c type. In these variants of dissociation, the objects to study are white clusters of partons.

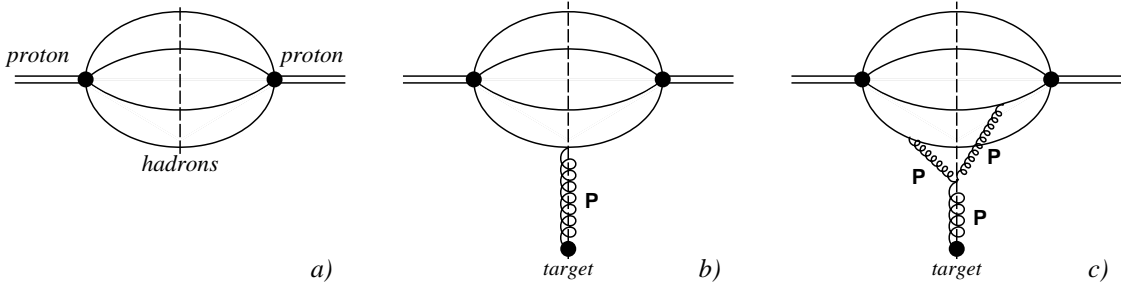


Figure 7: The cutting of diagrams (dotted lines) which illustrate Figs. 5 and 6. a) Self-energy block of the fast moving proton, which corresponds to four white domains in Fig. 5b. b) Pomeron (**P**) interaction with one hadron from the self-energy block, other three hadrons (or white parton domains in Fig. 6b) do not interact. c) Three-pomeron (**PPP**) interaction with two hadrons from the self-energy block; two other white parton domains (Fig.6c) are transformed into hadrons.

They are flying farther in p_z -direction separately and almost parallel, being not "disturbed" by the soft collision with target.

To be more illustrative, let us re-draw the pictures of Figs. 5a,b and Figs. 6a,b,c by using diagrammatic language.

We believe that the physics of picture 5a is not enigmatic: this is a comb of partons with the average multiplicity $\langle n_{parton} \rangle \sim 10^2 - 10^3$. If the coherence is not broken, the parton comb turns into the proton again. Soft interaction with the target violates the parton coherence, thus leading to the creation of the hadron comb, with the same order of multiplicity $\langle n_{hadron} \rangle \sim 10^2 - 10^3$.

The process shown in Fig. 5b provides us with a diversity of hadron production schemes. First, let us note that the white parton domain structure can result in the process similar to that given in Fig. 5a – to the production of a common comb with the multiplicity $\langle n \rangle_{parton} \sim 10^2 - 10^3$.

But, as was said above, with a noticeable probability partons shown in Fig. 5b may evolve in such a way that white domains do not lose their coherence – the self-energy part shown in Fig. 7a demonstrate just this case; correspondingly, on the diagrammatic language, we have four combs of partons, Fig. 8a.

Diagrams with soft interaction shown in Figs. 7b,c give rise to processes of Figs. 8b,c (or of Fig. 6b,c). Here one or two virtual hadrons have lost the coherent structure of their partons and dissipated into a number of hadron states.

Of course, the discussed correlated domains may be either produced or not – such a problem requires further investigations. In the recently performed experiment at LHC [6], a sort of pair correlations of hadrons have been observed, which, or at least a part of them, could have such a domain origin. To reveal the domain origin of produced hadrons, one should carry out more detailed study.

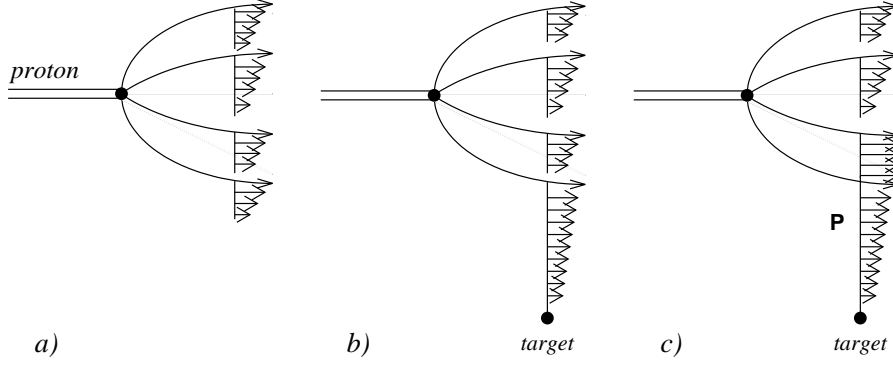


Figure 8: Left-hand side blocks of diagrams of Fig.7 after the cutting (dotted lines): a) Four combs of partons (four white clusters of Fig. 5b) originated after cutting the diagram 5a. b) Three combs of partons (three white clusters of Fig. 6b) and a comb of pomeron partons originated after cutting the diagram 7b. c) Partons originated after cutting the diagram 7c: two combs, corresponding to white domains of Fig. 6c, and that related to **PPP**-block.

Namely, it is necessary to measure the z distribution of particles moving in forward direction (that is particles with small p_{\perp}). The events with noticeable gaps as shown in Fig. 9b,c should indicate the existence of coherent domain of partons, of the type of shown in Figs. 6b,6c. One can expect that a number of events with high- p_z gaps must increase with energy, if the scheme of Fig. 5b is realized in hadron collisions in the TeV region.

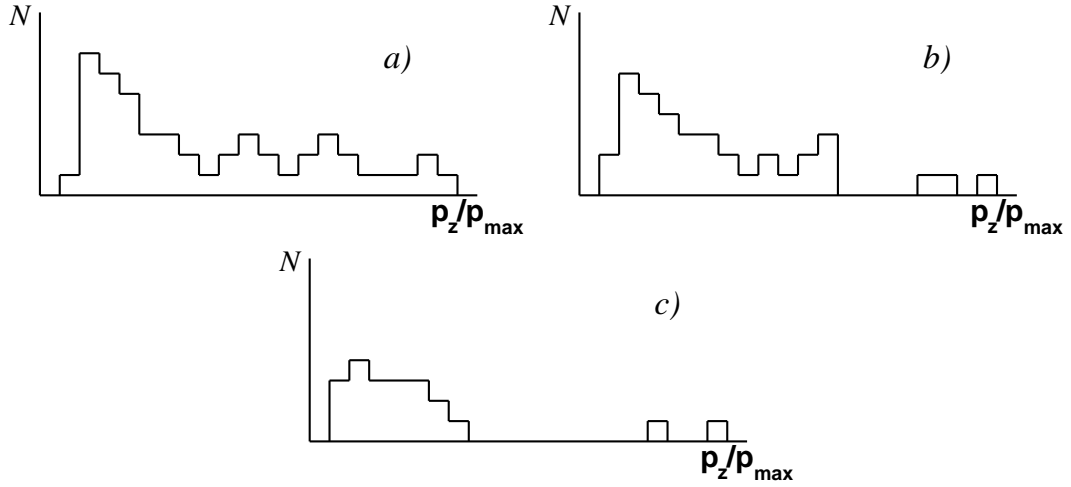


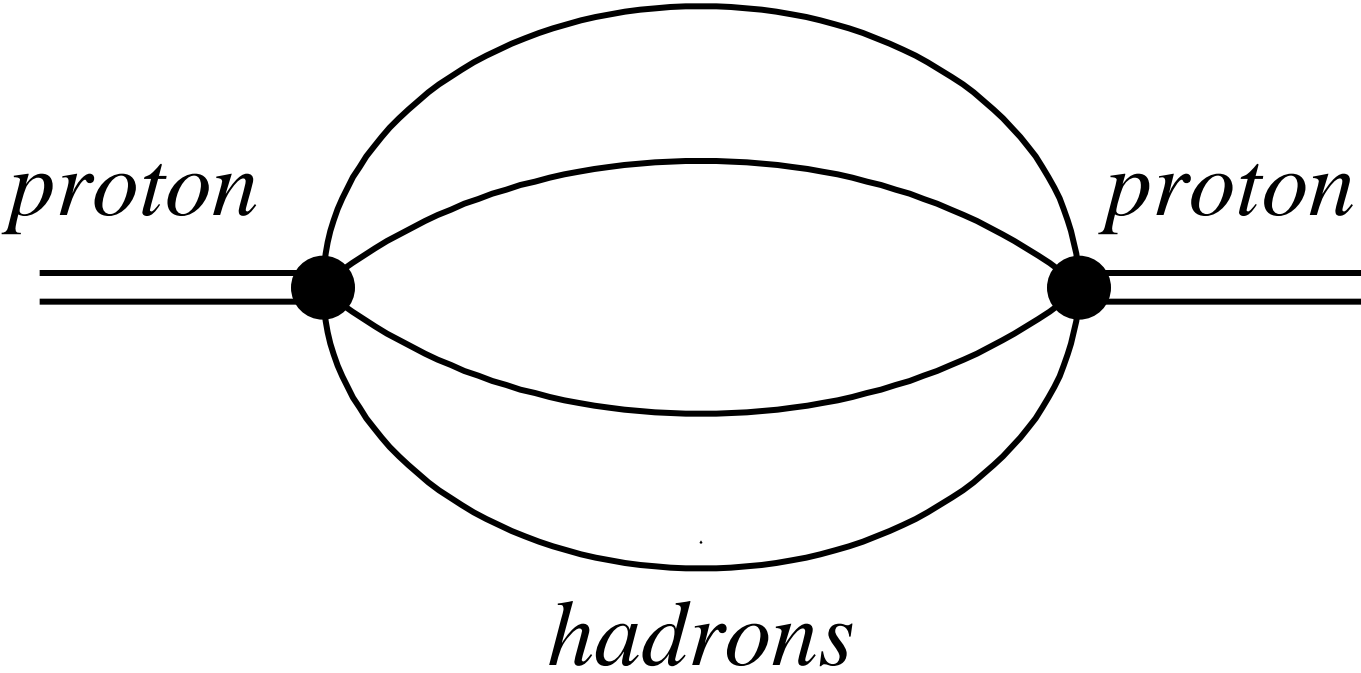
Figure 9: Possible p_z distributions of secondaries in processes, which correspond to Fig. 6b,c (or to cuttings of diagrams in Figs. 8b,c). Typical property of distributions b) and c) is that hadrons with a large fraction of $x = p_z/p_{initial}$ are separated from other secondaries.

Acknowledgement

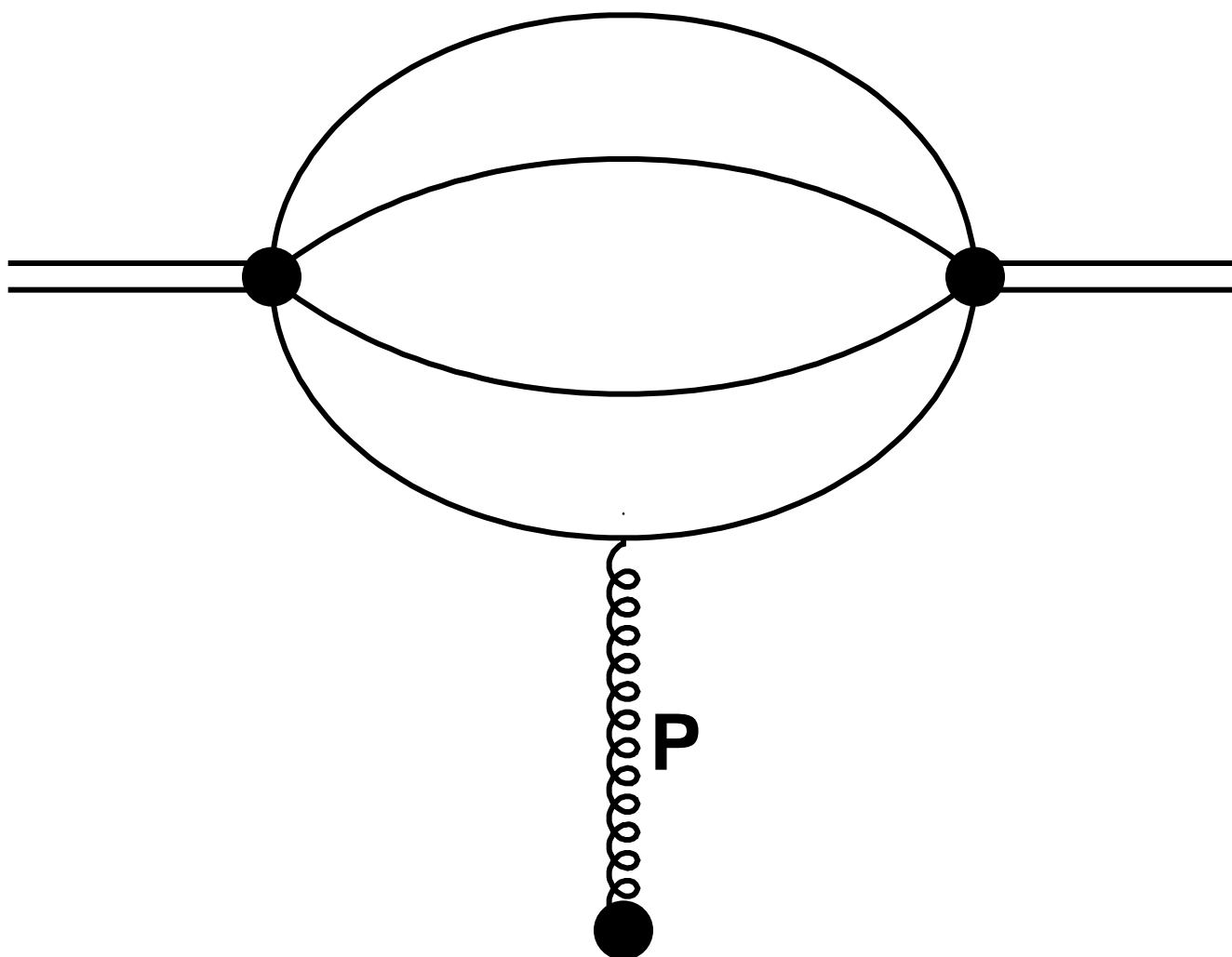
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a)



target

b)

